



## **Faculty of Electrical Engineering**

# **IMPACTS OF SOLAR PHOTOVOLTAIC SYSTEM ON DISTRIBUTION NETWORK PERFORMANCE**

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**IMPACTS OF SOLAR PHOTOVOLTAIC SYSTEM ON DISTRIBUTION NETWORK  
PERFORMANCE**

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in fulfillment of the requirements for the degree of Master of Science  
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## DECLARATION

I declare that this thesis entitled “Impacts of solar Photovoltaic system on distribution network performance” is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : ..... LAU CHEIW YUN .....

Date : .....

## **APPROVAL**

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature : .....

Name : ASSOC. PROF. DR. GAN CHIN KIM.

Date : .....

## **DEDICATION**

Special gratitude to my beloved parent, Lau Leong Sin and Lim Lai Keng for their enduring love, tenacity and patience throughout all my walks of life. And also to my siblings, Lau Cheiw Yuet and Lau Chin Kiat who have motivated and supported me throughout my life. I love you all.

## ABSTRACT

With the growth in energy demand and the depletion of fossil fuels, renewable energy resources have been seen as one of the most promising ways to sustain the future energy needs. However, the integration of renewables into the existing distribution networks can cause potential network problems. The issue is particularly acute if the renewable energy is generated from solar photovoltaic (PV) system with high variability. In this regard, this thesis deals with the modelling of a typical Malaysian distribution network that aims to analyze the impact of PV integration at distribution networks level. More specifically, the number of tap change for On-Load Tap Changer (OLTC) transformers is evaluated under various weather conditions; PV penetration levels as well as PV installed locations. The weather conditions were further categorized using variability index. In this way, the impact of solar variability can be properly assessed. The correlations of network losses and PV penetration levels have also been comprehensively analyzed. It is also important to highlight that actual solar PV generation data of various time resolution were collected and used in this work. This maintains the actual intermittency nature of PV generation. Furthermore, case studies have been performed for both low and medium voltage networks. The results suggest that sudden voltage variation and reverse power flow are the main concern of PV integration on the distribution network. The presented study shows that network losses are at the minimum level with a 50% PV penetration level. In addition, the findings suggest that high solar variability day could increase the tap change operations as much as 274% in average as compared to the network without PV system. In addition, a year-round analysis further suggests that the total annual tap change may operate 164% more frequently in average than a network without PV system.

## **ABSTRAK**

*Dengan pertumbuhan dalam permintaan tenaga dan kekurangan bahan api fosil, sumber tenaga boleh diperbaharui telah dijadikan sebagai salah satu cara yang paling digalakan untuk mengekalkan keperluan tenaga masa depan. Walaubagaimanapun, integrasi tenaga boleh diperbaharui pada rangkaian pengedaran yang sedia ada boleh menyebabkan masalah pada rangkaian. Isu-isu bertambah buruk sekiranya tenaga yang boleh diperbaharui yang dihasilkan daripada system solar fotovoltan (PV) dengan kepelbagaian yang tinggi. Dalam hal ini, tesis ini berkaitan dengan pemodelan rangkaian pengedaran Malaysia biasa yang bertujuan untuk menganalisis kesan integrasi PV di peringkat sistem pengedaran. Lebih khusus lagi, bilangan operasi On-Load Tap Changer (OLTC) telahpun dinilai dalam pelbagai keadaan cuaca; tahap penembusan PV serta lokasi PV dipasang. Keadaan cuaca telah dikategorikan menggunakan indeks kepelbagaian. Dengan cara ini, kesan kebolehubahan solar boleh dinilai dengan teliti. Profil voltan dan kerugian rangkaian juga dianalisis secara menyeluruh. Ia juga penting untuk fokus pada data generasi PV solar sebenar pelbagai resolusi masa telah dikumpulkan dan digunakan dalam kerja ini. Ini mengekalkan keadaan alam semula jadi yang sebenar bagi generasi PV. Tambahan pula, kajian kes telah dijalankan untuk kedua-dua rangkaian voltan rendah dan sederhana. Kajian ini menunjukkan bahawa variasi voltan secara tidak dijangkai dan aliran kuasa terbalik adalah isu utama integrasi PV pada rangkaian pengagihan. Kajian menunjukkan bahawa kerugian rangkaian adalah dalam tahap minima dengan 50% tahap penembusan PV. Di samping itu, kajian ini juga mencadangkan bahawa hari kebolehubahan solar yang tinggi akan menambahkan bilangan operasi OLTC dengan sebanyak 274% sebagai purata berbanding dengan rangkaian yang tiada pemasangan PV. Selain itu, analisis tahunan mencadangkan bahawa bilangan operasi OLTC tahunan bertambah sebanyak 164% dalam purata berbanding dengan bilangan operasi OLTC dalam rangkaian yang tiada pemasangan system PV.*

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## LIST OF ABBREVIATIONS

<b>AC</b>	Alternating Current
<b>BW</b>	Bandwidth
<b>CI</b>	Clearness Index
<b>COM</b>	Component Object Model
<b>CSI</b>	Clear Sky Index
<b>CSV</b>	Comma-Separated Value
<b>CT</b>	Current Transformers
<b>DC</b>	Direct Current
<b>DG</b>	Distributed Generation
<b>DHI</b>	Diffuse Horizontal Irradiance
<b>DLL</b>	Dynamic Link Library
<b>DNI</b>	Direct Normal Irradiance
<b>EPRI</b>	Electrical Power Research Institute
<b>EU</b>	European
<b>FiT</b>	Feed in Tariff
<b>GHI</b>	Global Horizontal Irradiance
<b>IEC</b>	International Electrotechnical Commission
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>I<sub>p</sub></b>	Primary Current

<b>LDC</b>	Line Drop Compensation
<b>LV</b>	Low Voltage
<b>MATLAB</b>	Matrix Laboratory
<b>MV</b>	Medium Voltage
<b>MW</b>	Mega Watt
<b>NERC</b>	North America Electric Reliability Corporation
<b>NERL</b>	National Renewable Energy Laboratory
<b>NLTC</b>	No-Load Tap Changers
<b>OLTC</b>	On-Load Tap Changers
<b>OpenDSS</b>	Open Distribution System Simulator
<b>p.u.</b>	Per Unit
<b>PV</b>	Photovoltaic
<b>RE</b>	Renewable Energy
<b>SEDA</b>	Sustainable Energy Development Authority Malaysia
<b>ST</b>	Surunhanjaya Tenaga
<b>TD</b>	Time Delay
<b>TNB</b>	Tenaga Nasional Berhad
<b>UNITEN</b>	Universiti Tenaga Nasional
<b>U<sub>p</sub></b>	Primary voltage
<b>U.S.</b>	United States
<b>UTeM</b>	Univeristi Teknikal Malaysia Melaka
<b>VI</b>	Variability Index
<b>VT</b>	Voltage Transformers
<b>WVM</b>	Wavelet Variability Model

## LIST OF PUBLICATIONS

### Journal

- [1] Lau, C. Y., Gan, C. K., Baharin, K. A., & Sulaima, M. F. (2015). A review on the impacts of passing-clouds on distribution network connected with solar photovoltaic system. *International Review of Electrical Engineering (I.R.E.E.)*, 10(3), 449–457. (*Scopus-indexed*)
- [2] Lau, C. Y., Gan, C. K., Z. Salam, & Sulaima, M. F. (2016). Impact of solar photovoltaic system on transformers tap changer in low voltage distribution network. *Energy Procedia*, *In-Press (Scopus Indexed)*

### Conference

- [3] Lau, C. Y., Gan, C. K., Tie, C. H., Baharin, K. A., & Sulaima, M. F. (2015). Passing-cloud effects of solar photovoltaic system on distribution network voltages. *2015 9<sup>th</sup> International Power Engineering and Optimization Conference (PEOCO)*, 551–555.

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background**

The world heavy reliance on fossil energy resources has brought numerous impacts on the environment such as climate change due to greenhouse gas emissions. To address this matter, Renewable Energy (RE) sources, such as solar, wind, biomass, tidal, and ocean thermal are being exploited as alternatives. Among these, the solar Photovoltaic (PV) appears to be the most promising option due to its inexhaustible resource from the sun. Driven by the governmental support and the advancement in PV technology, the number of PV installations have increased dramatically in the past few years. According to the futuristic expansion plans from various countries such as China, India, Germany, US, California, and Canada, there are many PV power projects installed with high PV capacity (Wong & Wills 2011; Bondre & Nambiar 2011; Grigoleit et al. 2014; Elkind et al. 2013; Small 2011). Furthermore, the total expected PV power generation capacity targeted in Europe is 84.4 GW by 2020 (Pearsall 2011).

In the Malaysia context, the introduction of Feed-in Tariff (FiT) scheme in year 2011 has prompted an increasing number of grid-connected PV system installation in Malaysia (KeTTHA 2011). In addition, a total of 985 MW of RE generations is targeted by the year 2015. In terms of PV development target, a total of 190 MW is expected to be connected to the utility grid by the year 2020 (The Economic Planning Unit 2010). The relative large integration of PV system in the distribution grid is expected to cause some network problems. For instance, the output of the PV panels is heavily depending on the solar irradiance level. In this regard, the